

**A COMBINED MGII/CAII SURVEY OF STELLAR MAGNETIC  
ACTIVITY IN THE SOLAR NEIGHBORHOOD**

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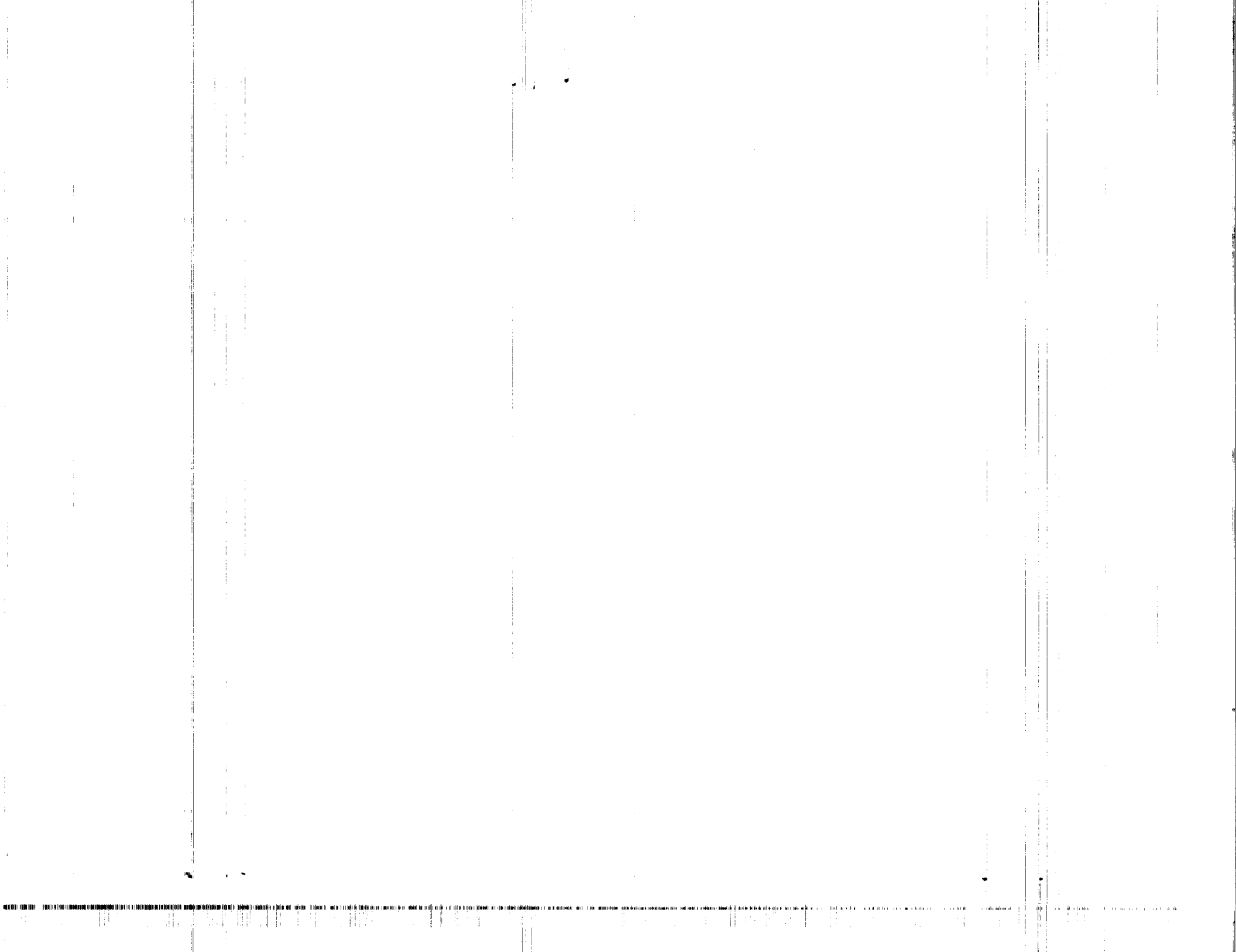
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## 1. Introduction

The HK Project database at Mount Wilson Observatory constitutes one of the largest and longest-running archives of stellar magnetic activity (Ca II H and K fluxes). The *IUE* archive extending only 15 years, roughly half the length of the HK Project, contains around 5000 spectra of Mg II h and k of over 700 lower main-sequence stars (acquired with the LWR and LWP cameras). We are using the *IUE* archive to create a database of stellar activity as derived from the chromospheric flux of the Mg II h and k lines in order to combine it with the existing database from Mount Wilson. Such a combined sample can provide greater insight into several areas related to stellar magnetic activity: 1) an extension of the Solar Neighborhood Survey to southern declinations and lower mass; 2) a further investigation of the distribution of magnetic activity among lower main-sequence stars and the Vaughn-Preston Gap; 3) a more detailed investigation of the distribution of long-term activity cyclic and extra-cyclic variation in older (i.e.,  $t \geq 2$  Gyr) lower main-sequence stars; and 4) an improved calibration of the activity-rotation and age-activity relationships.

## 2. Scientific Objectives

We wish to expand the database of stars for which chromospheric activity has been measured at Mount Wilson Observatory (Vaughan & Preston 1980) using the available archive of *IUE* Mg II h and k spectra. Approximately 800 lower main-sequence stars have been observed at Mount Wilson since 1979 as part of a Solar Neighborhood Survey. The survey extends to  $V \leq 7.5$  for declinations between  $+75^\circ$  and  $-28^\circ$ <sup>1</sup>. Over 700 G-M stars have been observed with the *IUE* over the entire sky, including Southern stars not accessible from Mount Wilson. Of these, approximately 200 stars have been observed by both telescopes, which would permit a relationship to be determined.

The successful intercomparison of the Mg II and Ca II chromospheric emission will augment current research in several areas, some of which are described below.

### 2.1. The Solar Neighborhood Survey

The first chromospheric survey of the solar neighborhood was done by Vaughan & Preston (1980) with a sample of 486 stars. Figure 1 shows a plot of the expanded database (780 stars), where the symbol size is proportional to the number of observations for each star and the solid

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<sup>1</sup>A handful of special objects have been sampled that are slightly fainter than  $V = 7.5$  with poor signal-to-noise ratio.

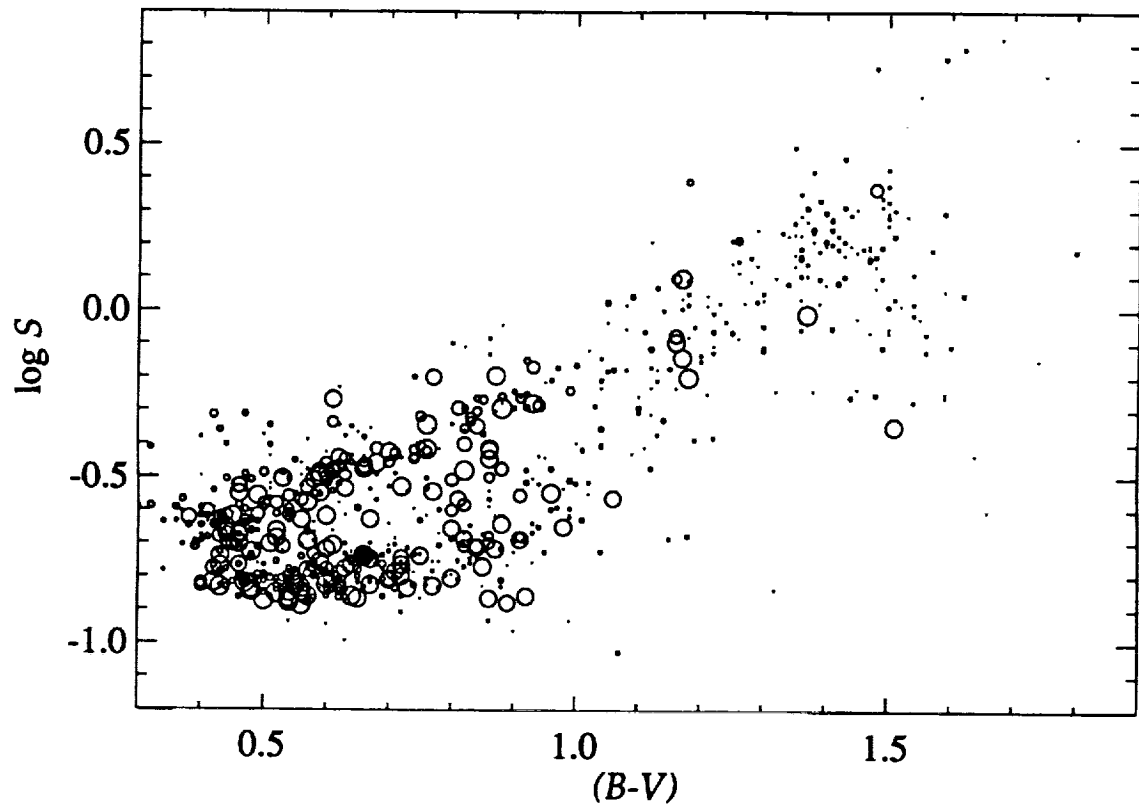


Fig. 1.— The  $\log S$ ,  $B-V$  diagram for the solar neighborhood (780 stars) as measured by the HK project through 1991. Symbol size is proportional to the number of observations.

circle is the Sun. The quantity  $S$  is a measure of the emission in the Ca II H and K lines normalized to the nearby continuum. The "Vaughan-Preston" Gap, an apparent lack of stars between the two populations of active and inactive G stars, is evident. This gap could be due to for non-steady star formation in the local solar neighborhood (Hartmann et al. 1984a), or as possibly a transitional state in the evolution of the magnetic dynamo (Durney, Mihalas & Robinson 1981) with a constant star formation rate in the local solar neighborhood. The quantity of observations of stars with  $B-V \geq 1.0$  decreases sharply, due to the magnitude limit of the HK instrument. Additional stars observed with the *IUE* will allow us to investigate the existence of the gap and extend the analysis to cooler stars.

### 2.1.1. Solar-like Stars

Figure 2 shows the solar neighborhood survey with the same symbols as in Figure 1. The quantity  $\log R'_{HK}$ , defined as the chromospheric loss in the H and K lines normalized to stellar bolometric luminosity (Middelkoop 1982) is plotted against stellar mass. The series of solid symbols shows the location of the Sun at different levels of activity, from activity maximum (top) to the low level estimated for the Maunder Minimum (bottom; Baliunas & Jastrow 1991).

Several southern stars that are not within the reach of Mount Wilson Observatory (e.g.,  $\alpha$  Cen,  $\beta$  Hyi) are frequently compared with the Sun. Incorporation of these stars into a combined chromospheric survey will permit comparison of the Sun to a large sample of lower main-sequence stars in addition to those close in mass and age to the Sun.

### 2.1.2. Late K-M Stars

As seen in Figure 1, the quantity of observations for stars redder than K2 decreases sharply. Over 400 K and M stars were surveyed with the *IUE*. The incorporation of many of these stars will contribute to a better assessment of the range of activity observed by these stars. K stars are particularly interesting because they exhibit activity cycles with larger amplitudes than earlier stars (Baliunas & Vaughan 1985). Little work has been done regarding the chromospheric behavior of dwarf M stars (e.g., Rutten et al. 1989), primarily due to the poor quantity of data available. As a result, most relationships involving chromospheric emission do not include M stars (e.g., Noyes et al. 1984). Increasing the sample will allow us to examine the extension of these relationships to later main-sequence stars. To determining the average level of activity required to accurately develop age/activity/rotation relationships (see below), it is necessary to sample the long-term behavior of the stars in the solar neighborhood. Such sampling will also describe the uncertainty in deriving these results from measurements of magnetic activity.

## 2.2. Long-Term Activity Behavior

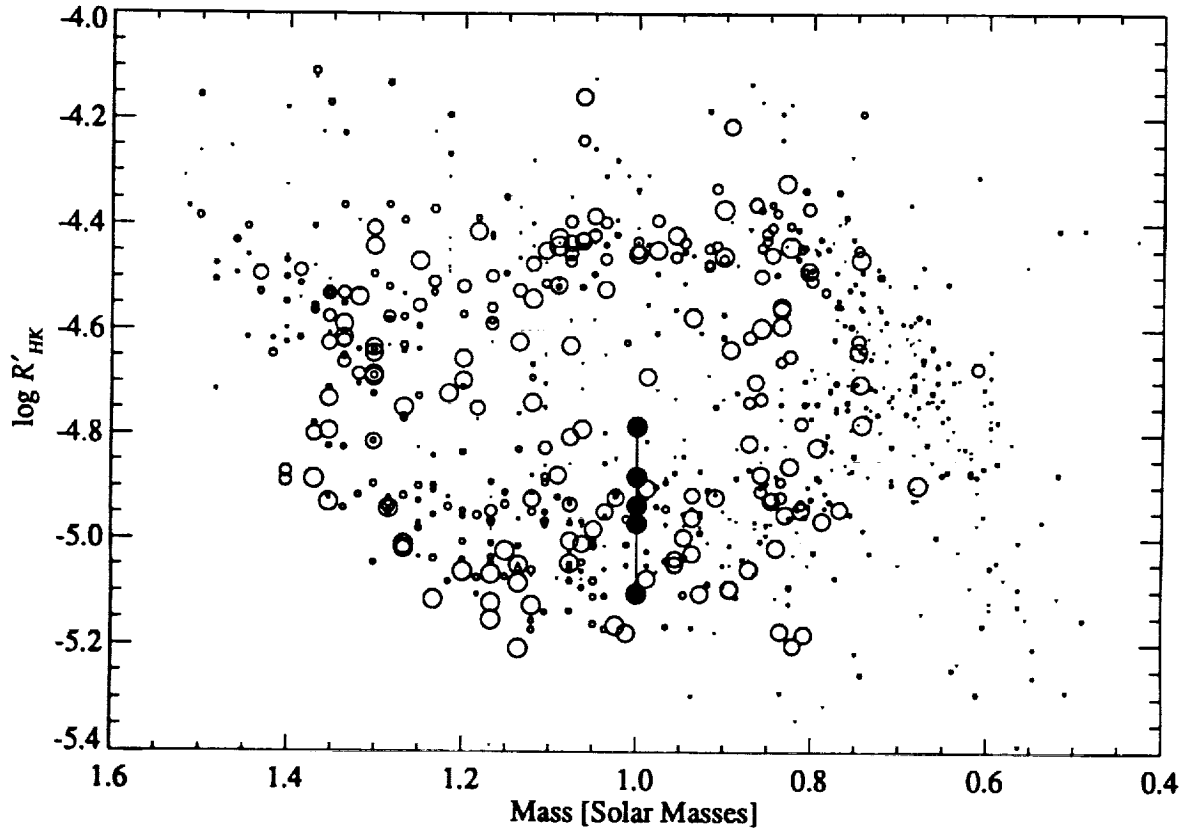


Fig. 2.— Chromospheric loss,  $R'_{HK}$  versus mass. The symbols are as in Figure 1. The filled circles represent the location of the Sun as it would appear at different activity levels. From top to bottom: activity at cycle maximum ( $S \sim 0.205$ ); mean activity for cycles 20 – 22 ( $S \sim 0.182$ , Donahue 1993); mean activity cycle 20 ( $S \sim 0.171$ , Wilson 1978); activity at cycle minimum ( $S \sim 0.165$ ); estimated activity during the Maunder minimum ( $S \sim 0.145$ , Baliunas & Jastrow 1991).

The HK Project archive extends back to 1966, or 27 years. The *IUE* observations span only half this length. However, since most of the stars in the HK solar neighborhood survey have only been observed sporadically, the available *IUE* observations can provide important information towards the detection of activity modulation in these stars. Stars that appear to have activity cycles based upon a handful of combined HK and *IUE* observations can be reactivated or inaugurated in the HK Project observing list, at a substantially lower priority than the stars observed since 1966, but observed frequently enough that the activity cycles can be monitored.

An extension of the solar neighborhood survey would be particularly helpful in the investigation of extra-cyclic activity variations in older lower main-sequence stars. Baliunas & Jastrow (1991) used a sample of 74 stars, restricted to those close to solar mass and in the lower activity portion of Figure 1 to infer the frequency and amplitude of Maunder minima.

Figure 3 shows the distribution of monthly means of activity for the older solar-like stars in their sample. The shaded sample shows the distribution of the solar activity over the last three activity cycles. The distribution of solar-like stars relies heavily upon those stars that have been observed the most frequently. The extension of this histogram with data from the *IUE* will dramatically improve the statistics of this distribution. Furthermore, the increased sample size will permit similar distributions to be made for late-G stars and K stars.

### 2.3. The Age/Activity/Rotation Relationships

Several studies have proven the existence of age-activity and age-rotation relationships (e.g., Skumanich 1972; Noyes et al. 1984; Soderblom, Duncan & Johnson 1991). Studies of these relationships using *IUE* have been done by Hartmann et al. (1984b), Simon, Herbig & Boesgaard (1985), and Simon (1990) using a few dozen stars. A long-term study of lower main-sequence rotation has existed at Mount Wilson since 1980. As of 1992, rotation has been measured for over 100 stars. While data from the *IUE* will generally not be useful for *determining* rotation, *IUE* data can be very helpful for pinpointing the mean levels of chromospheric activity for stars that have not been observed at MWO for which rotation might be measured by other means, for example, photometrically (e.g. Alphenaar & van Leeuwen 1982; Radick et al. 1987). These data could also identify stars that should be observed for the purposes of determining rotation, either at MWO if possible, or through the use of the Automatic Photoelectric Telescope (APT) located at Mt. Hopkins, if more feasible.

#### 2.3.1. Clusters

Observations of star clusters provide the best calibration of the age/activity/rotation relationships. Since the stars in a cluster are presumably coeval, any activity variety observed in similar stars should arise from long-term variations in the stars themselves, such as activity cycles

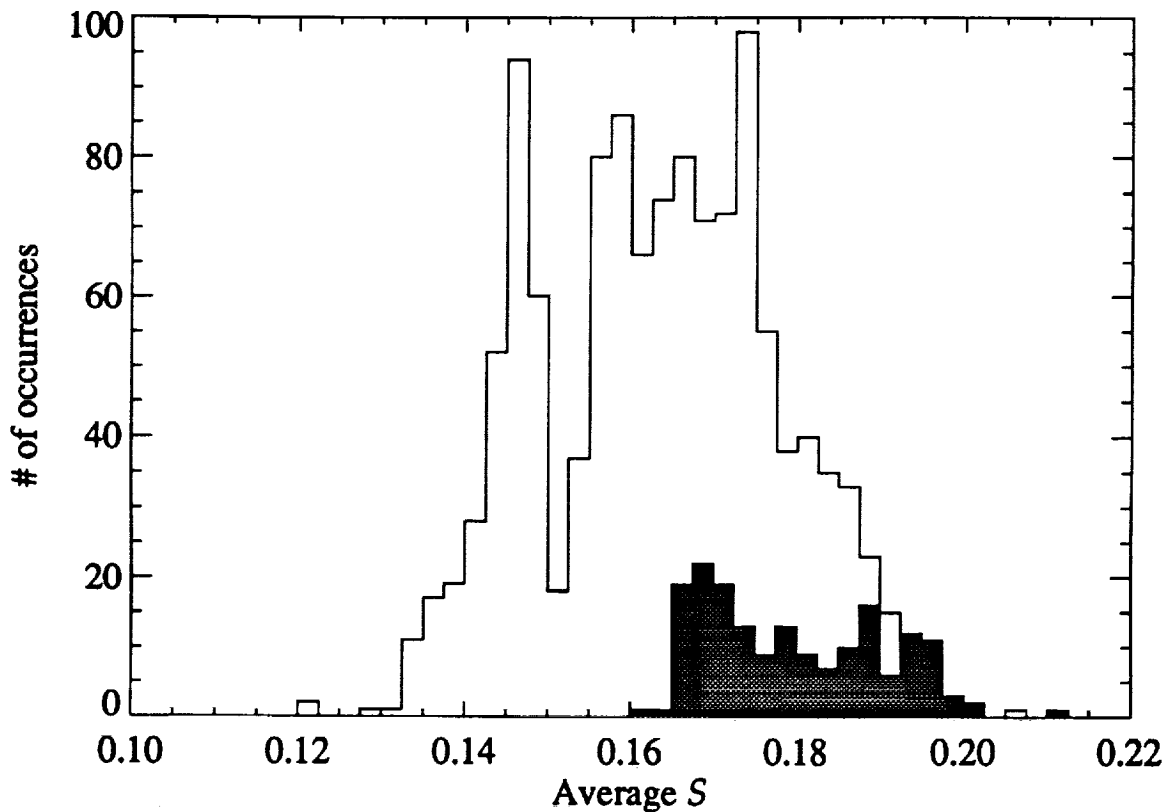


Fig. 3.— The distribution of magnetic activity in 74 solar-like stars. Each occurrence is the mean over 0.1 years. The broad peak at higher values of magnetic activity ( $S > 0.15$ ) corresponds to the broad distribution expected for stars varying with activity cycles. The narrow peak at lower activity ( $S < 0.15$ ) possibly represents stars sampled in Maunder minima. The filled histogram shows the behavior of the Sun measured similarly since 1966 (Wilson 1978; Keil 1992; Donahue 1993).



or extra-cyclic activity. Therefore a survey of these clusters can reveal two important parameters: 1) the mean activity level, which provides a useful indicator that can be calibrated to stellar age; and 2) the variance of activity observed and distribution of activity for the cluster stars, which implies the mean activity cycle amplitude and range of extra-cyclic activity.

The *IUE* has been used to survey several members of open clusters (e.g. the Hyades, Pleiades,  $\alpha$  Persei, etc.). The limitation of the HK instrument has permitted investigation of the Hyades and only cursory study of the F and early-G dwarfs in other clusters (e.g., the Pleiades, Coma, and the Ori Ic association).

### 2.3.2. Binaries

The components of visual binary systems offer another test of the age/activity/rotation relationships. Since both stars are presumably coeval, the chromospheric emission observed for each star should yield the same age, neglecting long-term variability in magnetic activity as seen for the Sun in Figure 2. The age differences observed, however, allow an independent estimate of the uncertainty in the age determined from chromospheric observations of single field stars. The *IUE* has observed the components of several binaries in the solar neighborhood, increasing the degree to which the age-activity relation can be calibrated.

## 3. Analysis

The *IUE* archive contains both high-resolution and low-resolution spectra. It should be possible to utilize both in this project. Many studies of the Mg II h and k lines from high-resolution *IUE* data (e.g., Blanco et al. 1982; Hartmann et al. 1984b; Oranje & Zwaan 1987) and low-resolution data (e.g., Barry & Schoolman 1982) have constructed measurements of the chromospheric loss in the h and k lines. Fanelli et al. (1990) have devised an intensity index,  $I(MgII)$ , which measures the integrated flux of the (blended) lines from low-resolution spectra. Smith et al. (1991) discuss the merits of this index as an indicator of stellar chromospheric activity. Many stars in the *IUE* archive have been observed at both high- and low-resolution, permitting a calibration between the two types of data.

The timing of this proposal fits in well with the current efforts to reprocess the existing *IUE* spectra for the *IUE* Final Archive, just completed for low-dispersion spectra. The resulting homogeneous data are ideally suited for comparison with the data in the similarly homogeneous HK Project archive. This study will make use of the improved signal-to-noise and photospheric corrections incorporated in the Final Archive which were previously unavailable.

We are in phase one of our three-step analysis, described below.

### 3.1. Phase 1: Establishing the Chromospheric Relationships

*IUE* spectra are being analyzed to measure the chromospheric loss in the Mg II h and k lines, or if better suited, using a chromospheric index such as the  $I(MgII)$  index of Fanelli et al. (1990). Objects that have been observed by both the HK and *IUE* Proect telescopes are being used to derive a relationship between the two observations. We would take advantage of time resolution, where available, to give multiple measures of chromospheric activity to improve the Mg II/Ca II relationship. We expect to publish a paper outlining the process and stars used to arrive at these relationships.

### 3.2. Phase 2: Application of the Relationships to the *IUE* Archive

Chromospheric activity would be measured for those stars only observed by the *IUE*. These stars would then be placed in a combined archive of magnetic activity. A revised and greatly expanded solar neighborhood survey would be produced.

### 3.3. Phase 3: Incorporation of the Combined Archives

The results of phases 1 and 2 would be used to enhance several long-term projects currently underway, particularly those described in Section 2. This effort will be incorporated into the several papers benefiting directly from the expanded survey. In addition, the additional *IUE* data will be used to identify objects that merit scrutiny in the future, and those observations will be scheduled.

As is the policy of the HK Project, our data will be available to interested scientists to assist in specific work or future collaborations.

## REFERENCES

- Alphenaar, P., & van Leeuwen, F. 1981, IBVS #1957.  
Baliunas, S.L., & Jastrow, R. 1990, *Nature*, 348, 520.  
Baliunas, S.L., & Vaughan, A.H. 1985, *ARA&A*, 23, 379.  
Baliunas, S.L., Vaughan, A.H., Hartmann, L., Middlekoop, F., Mihalas, D., Noyes, R.W., Preston, G.W., Frazer, J., & Lanning, H. 1983, *ApJ*, 275, 752.  
Baliunas, S.L., Horne, J.H., Porter, A., Duncan, D.K., Frazer, J., Lanning, H., Misch, A., Mueller, J., Noyes, R.W., Soyumer, D., Vaughan, A.H., & Woodard, L. 1985, *ApJ*, 294, 310.

- Barry, D.C. & Schoolman, S.A. 1982, ApJ, 261, 220.
- Blanco, C., Bruca, L., Catalano, S., & Marilli, E. 1982, A&A, 115, 280.
- Donahue, R.A. 1993, PhD. thesis, New Mexico State University.
- Durney, B.R., Mihalas, D., & Robinson, D.R. 1981, PASP, 93, 537.
- Fanelli, M.N., O'Connell, R.W., Burstein, D. & Wu, C.-C. 1990, ApJ, 364, 272.
- Hartmann, L., Soderblom, D.R., Noyes, R.W., & Vaughan, A.H. 1984a, ApJ, 276, 254.
- Hartmann, L., Baliunas, S.L., Duncan, D.K. & Noyes, R.N. 1984b, ApJ, 279, 778.
- Keil, S.L. 1992, private communication.
- Middelkoop, F. 1982, A&A, 107, 31.
- Noyes, R.W., Hartmann, L., Baliunas, S.L., Duncan, D.K., & Vaughan A.H. 1984, ApJ, 279, 763.
- Oranje, B.J. & Zwaan, C. 1985, A&A, 147, 265.
- Radick, R.R., Wilkerson, M.S., Worden, S.P., Africano, J.L., Klimke, A., Ruden, S., Rogers, W., Armandroff, T.E., Giampapa, M.S. 1983, PASP, 95, 300.
- Rutten, R.G.M., Schrijver, C.J., Zwaan, C., Duncan, D.K., & Mewe, R. 1989, A&A, 219, 239.
- Simon, T. 1990, ApJL, 359, L51.
- Simon, T., Herbig, G., & Boesgaard, A.M. 1985, ApJ, 293, 551.
- Skumanich, A. 1972, ApJ, 171, 565.
- Smith, G.H., Burstein, D., Fanelli, M.N., O'Connell, R.W., & Wu, C.-C. 1991, AJ, 101, 655.
- Soderblom, D.R. 1985, AJ, 90, 2103.
- Soderblom, D.R., Duncan, D.K., & Johnson, D.R.H. 1991, ApJ, 375, 722.
- Vaughan, A.H., & Preston, G.W. 1980, PASP, 92, 385.
- Vaughan, A.H., Baliunas, S.L., Middlekoop, F., Hartmann, L.W., Mihalas, D., Noyes, R.W., & Preston, G.W. 1981, ApJ, 250, 276.
- Wilson, O.C. 1978, ApJ, 226, 379.
- Young, C.A. 1870, Journ. Franklin Inst., 60, 232.

